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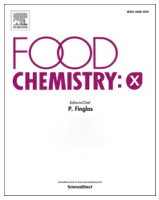

Quality analysis and assessment of representative sea buckthorn fruits in northern China

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ABSTRACT

Sea buckthorn (SB) primarily grows in northern China and is rich in nutritional components, making it popular among consumers. This study aims to select suitable SB varieties for processing by analyzing physicochemical components, color, taste, and volatile compounds. The results showed that the physicochemical content of Chinese SB from Gansu were as follows: total soluble solids 13.50 ± 0.37°Brix, titratable acidity 6.46 ± 0.39 %, ascorbic acid 578 mg/100 g, polyphenols 517 mg/100 g, and flavonoids 194 mg/100 g, which were higher than those of the other four SB samples; the content of organic acids was relatively abundant. Taste analysis via electronic tongue indicated that Chinese SB had the highest ANS (sweetness) value and the lowest SCS (bitterness) value, exhibiting the richest flavor. Gas chromatography-mass spectrometry analysis showed that Gansu Chinese SB had a rich variety of volatile components, totaling 74. In summary, Gansu Chinese SB is a variety suitable for processing.

1. Introduction

Sea buckthorn (SB) is a resilient plant that exhibits cold resistance, drought tolerance, and the ability to thrive in nutrient-poor soils, enabling it to adapt to harsh climatic conditions. In addition to offering ecological benefits in the region, SB serves as a valuable resource for economic development (Mei, Ma, Fu, & Cao, 2023). The world's largest SB resources are in China, which is about 2.7 million hm^2, mainly distributed in the northern part of China, such as Hebei, Gansu and Heilongjiang (He et al., 2023; Meng et al., 2024). SB is a plant that serves both medicinal and dietary purposes, containing a wealth of nutrients and bioactive compounds (Bal, Meda, Naik, & Satya, 2011). These bioactive compounds have physiological effects such as anti-tumor, hypolipidemic and cardiovascular protection (El-Sohaimy et al., 2022; Jastrząb & Skrzydlewska, 2019; Żuchowski, 2023).

SB products include: SB juice, SB beverage, SB jam (Nistor, Bolea, Andronoiu, Cotârleț, & Stănciuc, 2021), SB fruit oil, SB seed oil, SB leaf tea and so on (Vilas-Franquesa, Saldo, & Juan, 2020). SB oil, which is rich in fatty acids, demonstrates a range of beneficial activities, including the reduction of cholesterol levels, platelet aggregation, blood pressure, and blood glucose. Additionally, it exhibits antioxidant properties and displays anticancer, antimicrobial, antihistamine, antiviral, antispasmodic, and radioprotective effects. (C.-G. Ma, Zhao, Si, & Chen, 2021; Zheng, Shi, Zhao, Jin, & Wang, 2017). The most consumer product in the SB market is SB juice. SB juice is then added to other food products or made into drinks (Chen et al., 2023; X. Zhang et al., 2023). Qile Xia et al. reported the nutritional composition of SB juice, which includes the following values: total soluble solids (TSS) at 2.63 ± 0.06 %, total acidity at 6.34 ± 0.07 %, total sugar at 1.87 ± 0.00 %, vitamin C (Vc) at 356.90 ± 8.13 mg /100 mL, total phenols at 382.23 ± 2.58 mg GAE /100 mL, and total carotenoids at 0.36 ± 0.00 mg /100 mL. Additionally, the flavor profile of the juice comprises 37 esters, 9 terpenes, 4 aldehydes, 4 acids, 3 alcohols, and 1 ketone (Xia et al., 2023). SB berries contain these food chemical components, which contribute to their distinct tastes and flavors.

Currently, most of the SB juice in the Chinese market is relatively acidic and has an off-flavor, which makes it difficult for general consumers to accept the flavor. The purpose of this study is to analyze and evaluate the quality and flavor of characteristic SB varieties in the major SB producing areas in northern China, and to find suitable raw materials for processing the juice to meet the consumers' demand.

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2. Materials and methods

2.1. Raw material

SB (Fig. 1) was purchased in March 2023 and stored in a − 26 °C frozen storage. The species and origin were Heilongjiang ShenQiuHong (HLJ-SQH) SB, Heilongjiang Mengzhonghuang (HLJ-MZH) SB, Heilongjiang Chinese (HLJ-CHN) SB, Hebei Chinese (HB-CHN) SB, and Gansu Chinese (GS-CHN) SB.

2.2. Preparation of SB juice

SB berries were cleaned, crushed and filtered with 200 mesh to extract the juice. The juice was refrigerated at 0 °C.

2.3. Analysis of physical and chemical properties

Total soluble solid (TSS) content and titratable acidity (TA) were determined at 25 °C ± 1 °C by using a PAL-BX/ACID1 sugar–acid integrated machine (ATAGO, Co., Ltd. Tokyo, Japan). TSS was expressed as °Brix, and TA was expressed as g/ 100 g based on citric acid.

2.4. Analysis of color characteristics

Chromaticity values, including L* (brightness), a* (red-green), and b* (yellow-blue), were determined using a colorimeter (CR-400; Konica Minolta, Japan).

2.5. Analysis of nutritional quality

2.5.1. Determination of ascorbic acid

The ascorbic acid content was determined using the method specified in GB 5009.86–2016 (National Standard for Food Safety for the Determination of Ascorbic Acid in Foodstuffs, CN, USA).

2.5.2. Determination of total phenolics

The total phenol content of SB juice was measured using the Folin-Ciocalteu method (Velázquez-Estrada, Hernández-Herrero, Rüfer, Guamis-López, & Roig-Sagués, 2013). Furthermore, 5 mL SB juice was mixed with 20 mL of 80 % methanol solution, ultrasonicated for 15 min, and centrifuged at 10,000 rpm and 4 °C for 15 min. This process was repeated three times to consolidate the extracts, which resulted in the crude polyphenol extraction solution. After the polyphenol extract was diluted 10-fold, 0.4 mL of the extract was combined with 2 mL of a 10-fold diluted forintol reagent and 1.8 mL of 7.5 % Na_2CO_3 solution. Once the reaction was carried out at room temperature for 1 h, the absorbance was measured at 765 nm. The total phenol content was expressed as a milligram gallic acid equivalent per 100 g of the sample.

2.5.3. Determination of total flavonoids

The $AlCl_3$-$NaNO_2$ colorimetric method was used to determine the total flavonoid concentration in SB juice (Wu et al., 2021). After the SB juice was diluted 10-fold, 0.3 mL of 5 % $NaNO_2$ and 10 % $AlCl_3$ were successively added to 1 mL of the sample solution. The mixture was allowed to sit for 6 min each. To determine the absorbance value at 510 nm, 4 mL of 10 % NaOH was added to the sample. The sample was then fixed to 10 mL with distilled water and left for 15 min. Rutin was used as the standard sample for calculating the total flavonoid content.

2.6. Analysis of organic acid content

The organic acid content was determined using the methods outlined in GB 5009.157–2016 (National Food Safety Standard for the Determination of Organic Acids in Foods, CN, USA). SB juice samples (each weight: 5 g) were filtered through a 0.45-μm filter membrane. A high-performance liquid chromatography (HPLC) system with a photodiode array detector (HPLC-PDA; Waters Corporation, MA, USA) was used for the analysis. The chromatographic conditions were as follows: a ZORBAX Eclipse XDB-C18 column (4.6 × 250 mm, 5 μm); mobile phase, 0.1 mol L^{-1} H_3PO_4-methanol (97.5: 2.5, *v*/v); flow rate, 1.0 mL min^{-1}; injection volume, 10 μL, detection wavelength, 210 nm; and analysis time, 15 min.

Fig. 1. Representative SB in northern China.

2.7. Analysis of sensory quality

2.7.1. Electronic tongue

Before being used, the electronic tongue (*E*-tongue) (Astree II, Alpha M.O.S., Toulouse, France) was calibrated with a standard solution. Seven sensors were employed to detect taste. Each signal capture lasted 120 s. A wash sequence was established between each sample. The measurement was repeated three times for each sample. The data were processed using Alpha Soft V14.2.

2.7.2. Electronic nose

The Heracles II electronic nose (E- nose), which is fitted with the MXT-5 (a nonpolar column, 10 m × 0.18 mm, 0.4 μm) and MXT-1701 (a low-polar column, 10 m × 0.18 mm, 0.4 μm) flame ionization detectors (FIDs), is used for quickly analyzing the odor of SB. A 2-mL sample of the SB juice was placed in a 20-mL headspace vial and incubated at 60 °C for 20 min. The injection volume was 2000 μL, the injection rate was 125 μL s^{-1}, the temperature of the injection port was 200 °C, the outlet flow rate was 30 mL min^{-1}, the injection time was 45 s, the cleaning time was 200 s, and data acquisition time was 110 s. The data were processed using Alpha Soft.

2.8. Analysis of volatile organic compound

Volatile organic compounds (VOCs) were augmented and determined through head space-solid phase microextraction-gas chromatography–mass spectrometry (HS-SPME-GC–MS) as described by Zhang, J, et al. (J. Zhang et al., 2022), with minor modifications. First, a 5 mL sample was transferred to a 20 mL headspace. The vial was tightly sealed with a headspace threaded cap and a silica gel spacer, and placed on a magnetic stirrer. The headspace vials were equilibrated at 50 °C for 10 min. The volatile chemicals were adsorbed onto SPME fibers coated with 50/30 μm divinylbenzene/carboxen/polydimethylsiloxane for 30 min. Following extraction, the volatiles were thermally desorbed at 250 °C for 3.5 min in the injection inlet of the GC–MS system (Trace 1310/TSQ 8000 Evo, Thermo Scientific, Waltham, MA, USA). VOCs were separated using a TG-5MS elastic capillary column (30 m × 0.25 mm × 0.25 μm; Thermo Scientific, Waltham, MA, USA). Helium was employed as the carrier gas at a constant flow rate of 1.0 mL min^{-1}. The GC-oven temperature was initially set at 40 °C for 3 min, and then increased to 120 °C at 5 °C/min, and eventually increased to 250 °C at 10 °C/min for 4 min. The sample was injected in the 1/5 split mode by using high-purity helium as the carrier gas and a column flow rate of 1.2 mL min^{-1}. The mass detector was set to the electron impact mode (70 eV), with the transfer line and ion source at 250 °C and 280 °C, respectively. The extracted volatile compounds were identified by comparing the mass spectra with those in mass spectral libraries (NIST14). Using the peak area normalization method, we calculated the relative contents of various volatile compounds.

2.9. Statistical analysis

All experiments were conducted in triplicate. The data were presented as the mean ± standard deviation. $P < 0.05$ indicated a statistically significant difference. Data were analyzed using a one-way analysis of variance of SPSS Statistics 25 software (Chicago, IL, USA). Microcal Origin 2021 (Micro Software, Inc., MA, USA) and GraphPad Prism 8 (GraphPad Company, CA, USA) were used for charting and figure creation.

3. Results and discussion

3.1. The physicochemical properties of SB

The physical and chemical indices of SB from different varieties of the same origin differed significantly, whereas the difference in the physical and chemical indices of SB from other sources of the same variety was greater (Table 1). GS-CHN SB had a significantly higher TSS content (13.5°Brix) than the other four groups (<10°Brix). Additionally, GS-CHN SB had a significantly higher TA content (6.46 %) than the other four groups ($P > 0.05$).

3.2. The color of SB juice

Color is a significant factor determining the appearance of fruits and vegetables and their processed products. Carotenoids, anthocyanins, and chlorophylls are prevalent natural pigments in fruits and vegetables that confer good color to them (Santhirasegaram, Razali, George, & Somasundram, 2015). When carotenoids, anthocyanins, flavonoids, and other chemical components are included in SB fruits, these fruits develop a distinct hue. For example, when carotenoid content is high, SB fruits are largely yellow, but when anthocyanin content is high, the fruits are acidic and predominantly red. Fig. 2 shows that the difference in the color of SB juice between different varieties and origins is obvious but yellow. By contrast, the difference in color between GS-CHN SB juice and the other four groups is obvious and orange-red. Table 2 compares color differences among the five groups of SB juice. The greater the L*, the brighter the juice. The L* value was significantly greater for the HLJ-SQH SB juice than for the other five groups ($P < 0.05$). The higher the a* value, the more intense the red color. GS-CHN SB had a considerably higher a* value than the other groups ($P < 0.00001$), thus supporting the findings presented in Fig. 2. The b* value was larger, which indicated a greater yellow value. HLJ-SQH SB had the greatest b* value and the brightest yellow color.

3.3. The nutritional components of SB

Fig. 3 depicts the differences in ascorbic acid, total phenol, and total flavonoid contents in five distinct types of SB juice. SB is also known as “the treasure house of natural vitamins” because it contains the highest amount of ascorbic acid compared with any fruit or vegetable, three times that of kiwifruit, six times that of mandarin orange, and 200 times that of an apple (Makovics-Zsohár, Hegedűs, Stefanovits-Bányai, Rédei, & Papp, 2014; Zielińska & Nowak, 2017). Fig. 3(a) shows that the ascorbic acid content of the fruit juices varied considerably among the different varieties. GS-CHN SB (578 mg/100 g) had significantly higher ascorbic acid content than SQH and MZH. The ascorbic acid content was significantly higher in the GS origin than in the HB and HLJ origins ($P < 0.0001$).

Polyphenols, also described as the “seventh class” of nutrients, are vital antioxidants found in fruits and vegetables. They have various health-promoting physiological activities. An increase in polyphenol content is a sign of the improved antioxidant efficacy of fruits and vegetables (Bouarab Chibane, Degraeve, Ferhout, Bouajila, & Oulahal, 2019; Sytařová et al., 2020). SB polyphenols include approximately 20 different types of antioxidant compounds. Therefore, SB has substantial antioxidant and reducing properties. Moreover, these antioxidant compounds protect blood vessels, which aids the body’s defense against free radicals (Xu et al., 2007). The origin significantly affects the polyphenol content of SB among different varieties (Fig. 3(b)). The polyphenol

Table 1
Physical and chemical indicators of SB juice of different varieties from different origins.

Samples	TSS (°Brix)	TA (%)
HLJ-SQH	9.17 ± 0.12^{b}	4.11 ± 0.14^{b}
HLJ-MZH	6.97 ± 0.45^{d}	2.21 ± 0.12^{c}
HLJ-CHN	7.73 ± 0.26^{c}	1.96 ± 0.07^{c}
HB-CHN	9.07 ± 0.39^{b}	4.00 ± 0.17^{b}
GS-CHN	13.50 ± 0.37^{a}	6.46 ± 0.39^{a}

Note: different superscripts (a–e) indicate significant differences ($P < 0.05$) within a specific row.

Fig. 2. Appearance of different varieties of SB juice from different origins.

Table 2
Differences in the color of SB juice of different varieties from different origins.

Samples	L*	a*	b*
HLJ-SQH	62.13 ± 0.52^{a}	24.24 ± 0.12^{b}	59.49 ± 0.62^{a}
HLJ-MZH	56.73 ± 0.66^{b}	20.87 ± 0.34^{c}	50.20 ± 1.53^{b}
HLJ-CHN	50.44 ± 0.36^{d}	13.14 ± 0.24^{e}	44.98 ± 0.68^{c}
HB-CHN	55.04 ± 0.16^{c}	17.36 ± 0.51^{d}	49.36 ± 0.05^{b}
GS-CHN	54.98 ± 0.49^{c}	28.22 ± 0.29^{a}	57.57 ± 1.26^{a}

Note: different superscripts (a–e) indicate significant differences ($P < 0.05$) within a specific row.

content was significantly lower in SB from HLJ than in SB from HB and GS. The polyphenol content of GS-CHN SB (517 mg/100 g) was significantly higher than that of the other four groups.

Flavonoids are plant secondary metabolites with various biological activity. They are not produced by the human body and are typically derived through plants. Flavonoids are believed to be the key active and distinguishing component of SB. SB used as a medicinal health food is a good source of natural flavonoids for humans (Fatima et al., 2015) Two factors affect flavonoids present in SB: origin and variety. These factors can result in significant differences in the flavonoid content of SB juice among the five groups. The flavonoid content was generally higher in CHN SB than in the other two varieties (Fig. 3(c)). When the same species were found in different places, GS-CHN had the highest flavonoid content (194 mg/100 g), whereas HLJ-CHN had the lowest flavonoid content (119 mg/100 g).

3.4. Analysis of organic acids of SB

Natural organic acid is an acidic chemical component with physiological action contributing significantly to fruit flavor. Organic acids in the fruit are primarily responsible for the sour taste of SB, most notably malic acid, citric acid, and tartaric acid. Six organic acids were detected in SB juice. Fig. 4(b) presents the variations in the content of monomeric organic acids between different varieties of different origins. The malic acid content was significantly higher in GS-CHN SB than in HLJ-SQH and HLJ-MZH SB. By contrast, oxalic acid and tartaric acid contents in these two varieties were higher. Oxalic acid, a natural antioxidant detrimental to humans when ingested in excess, confers raw flavor in fruits and vegetables. The key components that impart acidic flavor to SB are malic and citric acids. These are ubiquitous organic acids found in fruits that give them a distinctly sour sensation (Coelho et al., 2018; Tkacz, Chmielewska, Turkiewicz, Nowicka, & Wojdyło, 2020). The low oxalic acid content of GS-CHN SB makes it less sour and astringent. The high malic acid and citric acid contents provide SB with a distinctive fruity taste. The high fumaric acid content in this origin variety, which, as a type of polycarboxylic acid, provides a good flavor. It can increase the total volatile fatty acid content and the organism's energy metabolism. GS-CHN SB exhibited the best physicochemical index of organic acid.

3.5. The sensory quality of SB

Fig. 5(a) displays the taste radar chart of five groups of SB juice obtained through the e-tongue taste analysis. This figure clearly illustrates the similarities and differences between the various types of SB juice from the sensory evaluation perspective. All five groups had high taste scores in the area, and the seven sensor signals were expressed as AHS (sour), ANS (sweet), SCS (bitter), CTS (salty), NMS (fresh), PKS (general), and CPS (general). GS-CHN and HLJ-SQH had higher sensor response values on sour and sweet, whereas GS-CHN had lower values on bitter. The difference between the other four varieties was smaller. The HLJ-MZH radar spanned the smallest area and had the most monotonous taste, whereas the GS-CHN radar spanned the most area and had the richest flavor. E-nose sensor values of the five groups were subjected to orthogonal partial least squares discriminant analysis (Fig. 5(b)). The five groups of SBs differed remarkably in volatile flavors. HB-CHN and HLJ-CHN had similar flavors. In Fig. 5(b), the second component (41.4 %) contributes more. While the volatile flavors of GS-CHN SB are different from those of the other four groups, CHN SBs are located in three or four quadrants, and the flavors are more similar.

3.6. The VOCs of SB

In total, 118 compounds and differences in the relative content between the compounds were identified through the GC–MS analysis and spectrogram search. (Table 3). Table 3 presents that the main aroma components in SB were esters (68 species), alcohols (13 species),

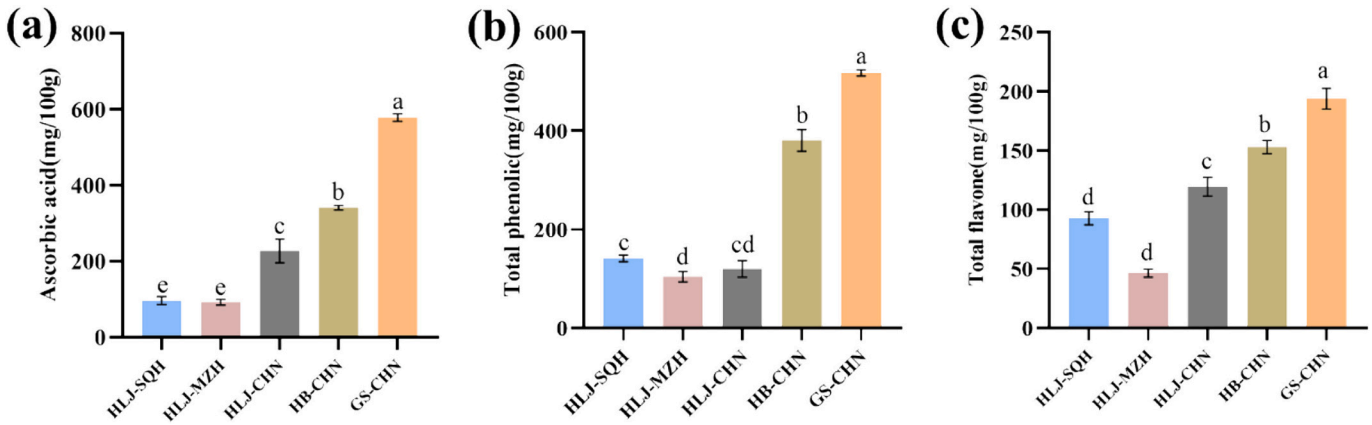

Fig. 3. Nutritional quality difference of SB juice: (a): ascorbic acid content; (b): total polyphenol content; (c): total flavonoid content.
Note: The same letter in the same graph indicates no significant difference, while different letters indicate a significant difference ($P < 0.05$).

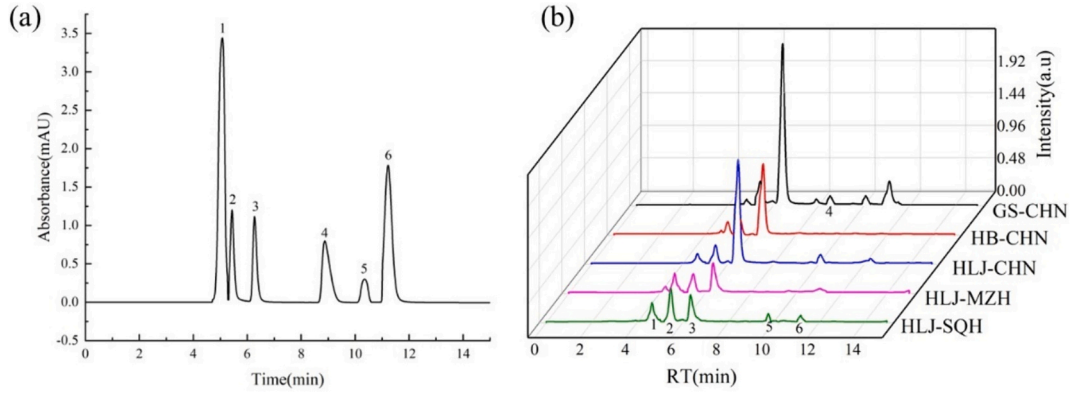

Fig. 4. Organic acid content HPLC chromatographic standard (a) and SB juice (b).
Note: (a) & (b): 1: oxalic acid; 2: tartaric acid; 3: malic acid; 4: citric acid; 5: succinic acid; 6: fumaric acid.

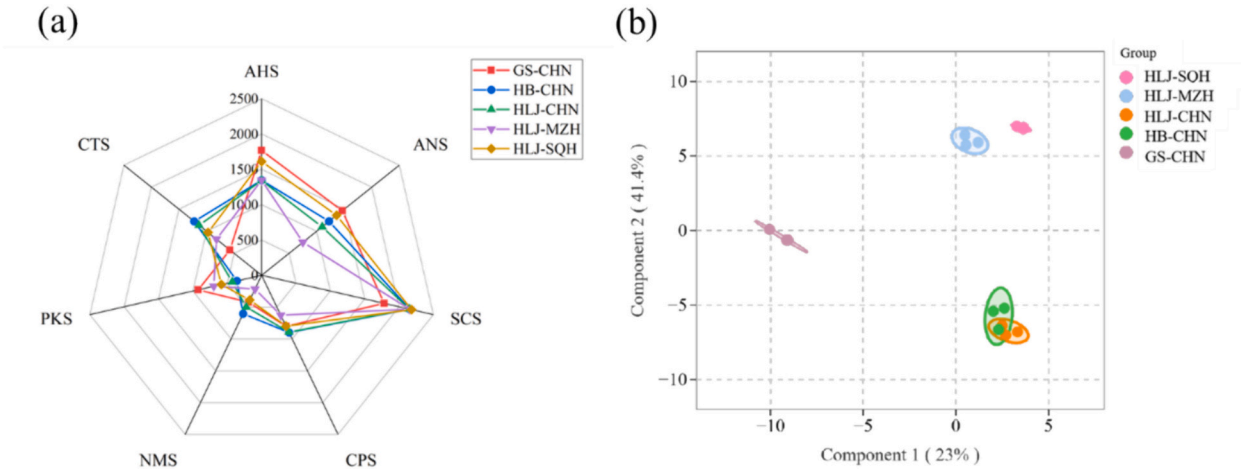

Fig. 5. Sensory quality difference of SB juice of different varieties from different origins: (a) *E*-tongue radar analysis chart; (b) E-nose sensor OPLS-DA.

terpenoids (6 species), aldehydes (6 species), ketones (3 species), acids (5 species), and other six categories, with esters and alcohols being the most common. This is consistent with the findings of Ma Xueying and Peng Bo (X. Ma, Yang, Marsol-Vall, Laaksonen, & Yang, 2020; Peng et al., 2023). Table 3 also shows that the VOCs of SB from diverse origins varied significantly in both types and contents. The VOCs were strongly related to the varieties, local geographic habitats, and meteorological circumstances. The ester components were primarily dominant among the SB VOCs, and the difference between the ester contents was significant. The HLJ-MZH ester content accounted for 87.81 % of the total content and GS-CHN ester content was only 61.81 %. The alcohol concentration of HLJ-CHN and GS-CHN SB was greater, accounting for 20.02 % and 21.47 % of the total alcohol concentration, respectively. Alcohols often impart soft, robust, slightly sweet aromas. Alcohols present in SB give the plant a more aromatic and mellow flavor. The VOC that imparts SB its scent is linalool. It is found in larger concentrations in all types of SB but is most prevalent in CHN SB. HB-CHN, GS-CHN SB contains 19.35 % and 16.99 % linalool, respectively. GS-CHN SB had higher concentrations of aldehydes (5.22 %) and terpenoids (5.27 %). Terpenoids contribute significantly to the flavor of some citrus and grapefruits, thereby increasing their fruity flavor and aroma. Additionally, terpenoids share structural similarities with oxygen-containing derivatives and hydrocarbons and therefore have a strong biological activity that offers an antioxidant function. This biological activity is linked to flavonoids, polyphenols, and other antioxidants found in GS-CHN SB, which indicates the high antioxidant concentration in GS-CHN. Octanal contributes to the oil flavor, which is owing to the high concentration of SB oil in GS-CHN. The acid concentration was higher in HLJ-SQH and HLJ-MZH SB than in CHN SB. However, the acids generated predominantly harsh and pungent aromas in the fruit aroma. Table 3 shows that GS-CHN SB had the greatest range of VOCs, of which 74 types were discovered, and high levels of all types of chemicals.

Because the total aroma values of SB juices in each group differed, the same volatile constituent, despite the differences in the relative content and contribution between the groups, did not represent the aroma intensity between the individuals. Flavor similarity between the groups was unknown. Consequently, a tree clustering diagram (Fig. 6 (a)) was created to enhance the depiction of variations in relative concentrations across samples based on peak area differences among the same substances. Fig. 6(a) depicts clustering dendrograms for each origin and species based on volatile chemicals. In clustering, related items are broken into groups or subsets by using a static distribution, so that objects in the same subset share some attributes. The dendrogram is the final display of the clustering findings. The scent and flavor of SQH and MZH are the most similar. Hence, these two types were classified in the first category. CHN SB from all three origins had similar flavors and was placed in the second category. In the second category, the flavors of HLJ and HB provenance were more comparable. According to the findings, greater variances were noted between varieties than between origins. Li Yanping et al. found that discrepancies in the genetic makeup of various cultivars have a greater influence on volatile components than objective circumstances such as planting site, temperature, and sunlight exposure(Beaulieu, Stein-Chisholm, & Boykin, 2014; Qian, Zhou, Magana, & Qian, 2022).

Table 3
Analysis of volatile components of SB juice of different varieties from different origins.

Number	Compound	Rt (min)	Relative content(%)				
			HLJ-SQH	HLJ-MZH	HLJ-CHN	HB-CHN	GS-CHN
Esters			**84.26**	**87.81**	**78.92**	**75.66**	**61.81**
1	Ethyl acetate	2.17	–	–	0.19	–	0.35
2	Ethyl 2-methylpropionate	4.46	–	–	–	–	0.26
3	Ethyl Butyrate	5.66	0.41	0.22	0.49	–	0.13
4	Ethyl 2-methylbutyrate	7.38	1.49	2.00	1.42	0.33	0.82
5	Ethyl isovalerate	7.53	2.97	4.39	3.52	0.83	1.68
6	Isobutyl isoacetate	9.16	–	–	–	1.23	0.82
7	3-Methyl-1-methylethyl butyrate	9.21	–	0.95	0.91	–	–
8	Butyl butyrate	10.1	–	–	–	0.13	–
9	Ethyl 3-methyl-2-butenoate	10.57	0.25	0.21	0.34	–	–
10	Butanoic acid, 1-methylpropyl ester	11.16	–	–	0.59	0.94	1.89
11	Butyl 2-methylpropanoate	11.19	–	0.22	–	–	–
12	Propyl 3-methylbutanoate	11.73	–	0.14	0.12	–	–
13	Ethyl 3-hydroxy-3-methylbutanoate	11.96	0.27	0.24	–	–	–
14	Ethyl 2-hydroxy-3-methylbutanoate	12.59	0.26	0.19	0.36	0.11	0.39
15	3-Methyl-4-(1,3,3,3-tetrafluoro-2-methoxycarbonyl -propenyl sulfonyl)-phenyl benzoate	12.67	–	–	–	–	0.33
16	methyl 12,15-octadecadienedioate	13.14	–	–	–	–	0.11
17	2-methyl-1-methylpropyl butyrate	13.32	–	–	–	–	2.83
18	Butyl 2-methylbutyrate	13.34	–	0.84	1.52	2.03	–
19	1-Methylpropyl Valerate	13.61	–	13.98	10.88	12.17	12.53
20	Ethyl hexanoate	14.13	0.14	3.88	5.14	8.24	12.30
21	Isobutyl isovalerate	14.43	0.10	1.16	1.89	2.12	0.15
22	Isopentyl isobutyrate	14.89	–	0.46	1.66	1.73	0.94
23	1-Methylethyl Caproate	15.97	–	0.24	0.23	0.43	–
24	Isoamyl Butyrate	16.98	–	0.20	0.46	0.47	0.30
25	Butyl (E)-2-methyl-2-butyrate	17.44	–	–	–	–	0.11
26	2,3-Dimethyl-4-hydroxy-2-butenolide	17.96	–	–	–	0.22	–
27	ethyl heptanoate	18.97	0.89	1.30	1.59	2.13	1.02
28	Methyl 2-oxohexanoate	19.17	–	0.27	2.40	–	–
29	Isoamyl isovalerate	19.4	1.71	15.66	25.23	22.40	4.04
30	Methyl caprylate	20.24	0.15	0.45	–	–	–
31	Butyl hexanoate	20.53	13.21	8.79	6.25	1.65	1.96
32	(Z)-3-Hexenyl 2-methylpropanoate	20.12	–	–	0.09	0.14	–
33	Hexyl Butyrate	21.34	0.09	0.17	0.11	0.11	0.17
34	Isobutyl Caproate	21.46	0.10	0.21	0.17	0.24	0.07
35	Ethyl Benzoate	22.25	7.66	2.85	0.07	0.38	–
36	3-Methyl-3-methylbutyl 2-butyrate	22.99	0.11	0.10	0.12	–	0.20
37	ethyl cis-4-octenoate	23.31	1.49	0.73	0.49	0.48	0.82
38	2-methyl-2,6-di-tert-butyl-4-methylphenyl cyclopropanecarboxylate	23.54	–	–	–	0.21	–
39	Ethyl caprylate	23.68	13.38	9.62	1.01	1.69	2.15
40	Isopropyl Benzoate	24.12	–	–	0.13	0.22	0.25
41	Butyl Heptanoate	25.15	–	0.12	0.11	0.26	0.18
42	Isopropyl caprylate	25.31	–	0.20	0.14	0.40	0.13
43	Hexyl 2-methylbutyrate	25.46	0.28	0.22	0.22	0.36	0.72
44	Hexyl 3-methylbutyrate	25.7	0.19	0.35	0.16	0.23	0.22
45	Isopentyl caproate	26.1	6.51	1.37	0.52	0.61	0.22
46	2-Methylbutyl hexanoate	26.21	1.41	2.53	0.64	0.81	0.61
47	6-Methyl-4-hepten-1-yl 2-methylpropanoate	26.44	–	0.12	0.77	1.07	0.72
48	6-Methyl ethyl 2,4-heptenoate	27.38	0.21	–	–	–	–
49	Ethyl nonanoate	28.23	–	0.16	0.13	–	–
50	Isobutyl Benzoate	28.54	0.21	2.32	1.56	5.16	7.08
51	sec-butyl benzoate	28.85	–	0.13	–	–	–
52	Isobutyl 3-octanoate	29.27	–	–	0.13	0.30	0.15
53	Isobutyl n-octanoate	29.56	0.14	1.48	0.80	1.28	0.84
54	2-Methylheptyl Butyrate	29.85	–	–	–	0.13	0.22
55	6-Methylhept-4-en-1-yl 2-methylbutanoate	30.43	–	0.23	0.88	–	1.31
56	2,4-Dimethylpentan-3-yl 2-methylbutyrate	30.49	–	0.13	–	–	–
57	6-Methylhept-4-en-1-yl 3-methylbutyrate	30.63	0.15	0.68	2.07	1.92	0.43
58	Ethyl trans-4-decenoate	31.71	2.07	0.45	–	–	–
59	Hexyl hexanoate	31.93	0.49	0.41	0.36	0.14	0.16
60	Ethyl decanoate	32.3	3.14	1.32	0.29	0.18	0.33
61	Benzyl valerate	32.4	–	–	–	0.11	–
62	Isoamyl Benzoate	33.86	22.62	5.36	2.77	2.08	1.88
63	3-Methylbutyl Caprylate	34	0.21	0.33	–	–	–
64	Ethyl 2,4-decadienoate	34.81	0.57	–	–	–	–
65	Hexyl caprylate	37.94	0.16	–	–	–	–
66	Ethyl Laurate	38.28	0.93	0.35	–	–	–
67	Decanoic acid 3-methylbutyl ester	39.64	0.32	–	–	–	–
68	Decyl Butyl Phthalate	46.6	–	0.12	–	–	–
Alcohols			**8.86**	**7.09**	**15.99**	**20.02**	**21.47**
69	tert-Butanol	2.07	–	0.19	0.22	0.34	0.42
70	3-Methyl-1-butanol	3.97	0.25	0.32	0.22	–	–

(*continued on next page*)

Table 3 (*continued*)

Number	Compound	Rt (min)	Relative content(%)				
			HLJ-SQH	HLJ-MZH	HLJ-CHN	HB-CHN	GS-CHN
71	n-Pentanol	4.07	–	–	–	–	0.23
72	n-Hexanol	8.44	0.18	0.21	–	–	–
73	Heptanol	8.54	–	–	0.18	–	–
74	2-Methyl-6-hepten-1-ol	14.03	–	–	–	–	0.39
75	cis-α, α-5-Trimethyl-5-vinyltetrahydrofuran-2-methanol	17.64	–	–	–	–	0.79
76	n-Octanol	17.88	–	–	0.17	–	0.81
77	trans-2-Decenol	18	–	0.20	–	–	–
78	Linalool	19.3	8.27	5.57	12.12	19.35	16.99
79	2,4-Dimethyl-3-pentanol	22.55	–	–	1.10	–	–
80	4-Terpineol	22.73	0.17	0.60	1.81	0.20	0.92
81	α-Terpineol	23.45	–	–	0.16	0.14	0.93
Aldehydes			**0.90**	**0.50**	**0.47**	**2.11**	**5.22**
82	Hexanal	5.6	–	–	–	–	0.16
83	Heptaldehyde	9.54	0.11	0.16	0.47	0.68	1.89
84	Benzaldehyde	12.47	0.40	0.35	–	–	0.28
85	Octanal	14.24	–	–	–	1.42	2.89
86	trans-2-Octenal	17.05	0.27	–	–	–	–
87	Phenylpropionaldehyde	20.42	0.11	–	–	–	–
Acids			**4.80**	**2.20**	**0.79**	**0.46**	**1.05**
88	Acetic acid	3.04	–	–	–	–	0.19
89	2-Hydroxy-2-methylbutyric acid	10.35	0.08	0.13	–	–	0.11
90	β-Hydroxyisovaleric acid	18.44	–	0.37	0.29	0.20	0.74
91	Octanoic acid	24.16	–	0.59	0.29	0.26	–
92	cis-5-dodecenoic acid	37.61	4.72	1.12	0.21	–	–
Terpenes			**0.29**	**0.54**	**1.29**	**0.91**	**5.27**
93	β-Pinene	15.31	–	0.16	0.49	0.33	2.28
94	trans-β-Pinene	15.89	–	–	0.20	0.24	0.79
95	Basilene	16.39	0.15	0.20	–	–	1.07
96	Terpinene	16.82	0.15	0.19	0.43	0.23	0.36
97	Terpinolene	18.25	–	–	0.17	0.12	0.53
98	α-Sclerocene	34.99	–	–	–	–	0.24
Ketones			**0.37**	**0.58**	**0.41**	**0.38**	**0.92**
99	1,2-Diphenylethanedione	29.68	–	–	–	0.12	–
100	α-Violanone	33.42	–	0.18	0.05	–	–
101	β-Violanone	35.57	0.37	0.40	0.35	0.26	0.92
Others			**0.49**	**1.28**	**2.14**	**0.47**	**4.26**
102	2,4,5-Trimethyl-1,3-dioxolane	3.69	–	–	–	–	0.42
103	Octane	5.45	–	–	–	–	0.15
104	Hexamethylcyclotrisiloxane	6.31	–	–	0.18	–	0.18
105	Ethylbenzene	7.7	–	–	–	–	0.11
106	Parylene	8.06	–	0.50	0.83	–	0.32
107	Styrene	8.99	–	–	–	–	0.46
108	m-Xylene	9.02	–	0.27	0.49	–	–
109	3,5-Dimethylphenol	10.98	–	–	–	–	0.22
110	O-umbelliferyl hydrocarbons	15.17	0.08	0.13	0.13	–	0.11
111	3,6-Dihydro-4-methyl-2-(2-methyl-1-propenyl)-2H-pyran	21.6	–	–	–	–	0.91
112	Decamethylcyclopentasiloxane	21.71	–	–	0.11	0.08	–
113	1,8-Cyclopentadecadiyne	25.03	–	–	0.28	–	0.28
114	Tridecane	28.18	–	–	–	–	1.09
115	Hexanoic anhydride	35.27	0.13	0.24	–	–	–
116	2-Acetylfuran	35.45	0.16	–	–	–	–
117	2,4-Di-tert-butylphenol	36.38	–	0.14	0.13	0.15	–
118	Hexadecamethylcycloalkylsiloxane	40	0.13	–	–	0.24	–

Note: "-" means not detected or a relative content of <0.1 %.

A correlation analysis of 15 unique characteristic compounds in the five groups of SB juice was performed (Fig. 6(b)), with red indicating a positive correlation and blue indicating a negative correlation. The circle's size indicates the correlation's strength. Numbers inside the circles denote correlation values. Flavor differences between these five groups of SB juice were most strongly correlated with ethyl isovalerate, ethyl hexanoate, ethyl benzoate, ethyl caprylate, and isoamyl benzoate. Linalool exhibited the strongest association with isoamyl benzoate, whereas ethyl caproate had the strongest correlation with ethyl benzoate. Fragrance composition variability may primarily occur due to the conversion of esters, alcohols, and aldehydes generated by metabolites during fruit ripening owing to geographic and structural changes across types and origins(Huang et al., 2024).

4. Conclusions

The study analyzed and evaluated the nutritional quality, physicochemical properties, and sensory characteristics of representative sea buckthorn fruits from Northern China, specifically HLJ-SQH, HLJ-MZH, HLJ-2HN, HB-CHN, and GS-CHN. From them, we chose the best SB berries for processing. The findings revealed that GS-CHN SB had more vitamin C, flavonoids, polyphenols, organic acids, and other biologically active components, and was of higher quality in terms of color and shine, with a distinctive orange-red hue. *E*-tongue technology revealed that GS-CHN SB had a low bitter value and a sensory quality more in agreement with customer preferences. Using e-nose and HS-SPME-GC–MS techniques, the flavors of the five groups of SBs were well differentiated. GS-CHN SB had considerably more variety of volatile constituents, and the

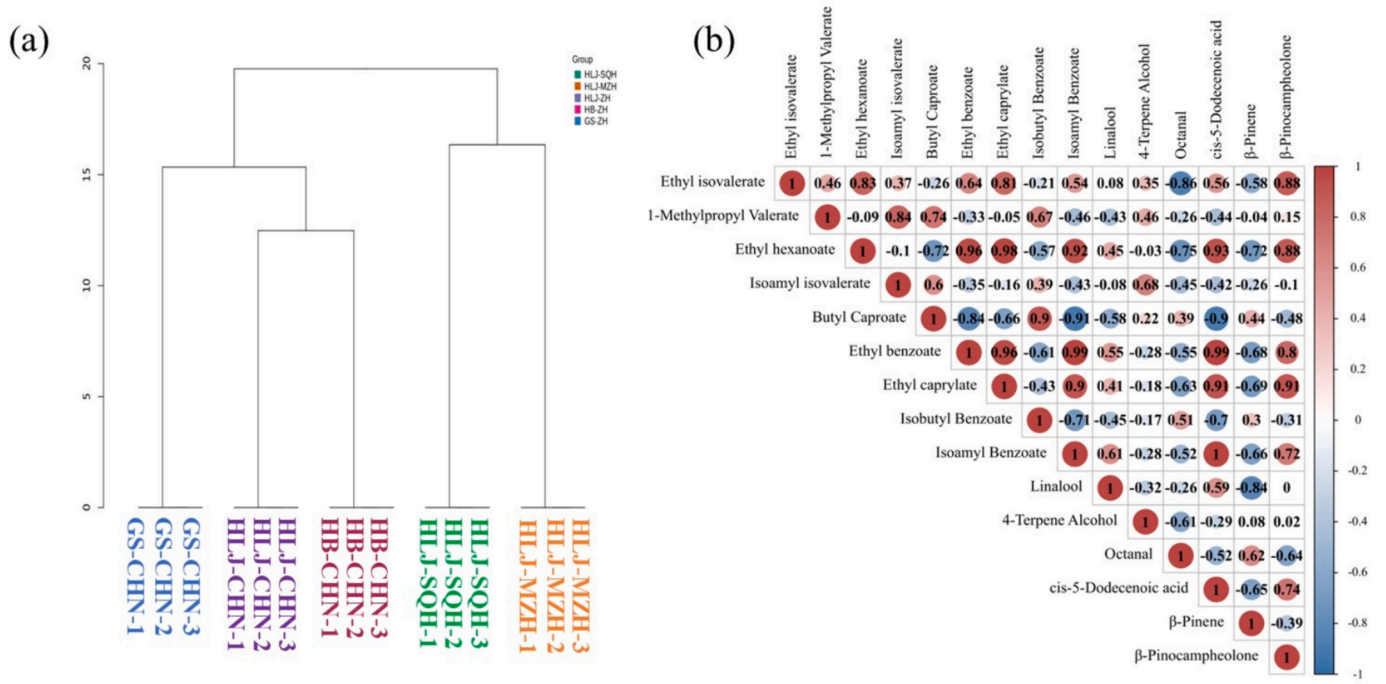

Fig. 6. Tree clustering plot (a) and correlation thermogram of characteristic volatile compounds (b) of flavor of SB juice from different varieties from different origins.

contents of the characteristic flavor substances of SB, such as linalool, ethyl hexanoate, β-pinene, and β-pinene, were all higher. The study findings can be widely applied to SB production practices and serve as theoretical references for related research in the future.

CRediT authorship contribution statement

Zhiwei Zhang: Writing – review & editing, Writing – original draft, Supervision, Project administration, Funding acquisition, Data curation, Conceptualization. **Yixuan Chen:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Zhixi Chen:** Investigation, Resources. **Zhenhong Gao:** Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Yuying Cheng:** Supervision, Investigation. **Kunsheng Qu:** Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors are unable or have chosen not to specify which data has been used.

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